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DEVELOPMENT OF A CLASSIFIER OF BENEFICIATION WASTE FOR THE FORMATION OF MAN-MADE DEPOSITS

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Abstract. The authors of the article consider the current state of tailing dumps of mining and processing plants in Kryvyi Rih, present the particle size distribution of the Central GOK's tailings, the volume and mass of particles of useful component and barren rocks of different fractions of beneficiation waste. It has been shown that over many decades of operation of Kryvyi Rih GOKs, huge masses of beneficiation waste have accumulated in tailings ponds covering an area of approximately 10 thousand hectares, which are estimated at 5–8 billion tons with a total iron content of 14–18% and can be considered technogenic deposits.

According to the results of the research, it was determined that today, for the sustainable development of Kryvyi Rih, an important area is the extraction of anthropogenic mineral raw materials from tailings as formed by man-made placers in the process of beneficiation waste storage, by minimizing both costs and negative environmental impact. Therefore, the development of a classifier of beneficiation waste for the formation of technogenic placers by selective extraction useful component from the flow of beneficiation waste during their hydraulic transportation from the beneficiation plant to the place of their separate storage.

It has been established that the mass fraction of barren rocks in the productive layer is 1.5–1.8 times less than that of the potentially productive layer. The mass fraction of unproductive layer is 12.5%, consists only of barren rocks. The results of the studies have shown that the parameters of the granulometric composition of the beneficiation waste of the Kryvbas mining and processing plant can vary significantly from one another, and therefore it is necessary to determine the upper limits of the weighing of mineral particles and the qualitative composition of each of the separated layers of the hydromixture based on the actual indicators of each of the mining and processing plants. A classifier has been developed that separates the flow of the beneficiation waste hydromixture into three components with selective extraction of the productive layer. The use of the classifier developed by the authors for the selective extraction of the productive layer with a useful component from the total flow of the hydromixture will allow achieving the set goal, namely: ensuring the possibility of forming a man-made deposit with a high content of useful minerals.

Keywords: beneficiation waste, tailings, granulometric composition, classifier, productive layer.

1. Introduction

Ukraine ranks seventh in the world in terms of mineral reserves. Kryvbas is one of the largest mining regions, where the richest and largest iron ore deposits are being developed. The mining and processing plants of Kryvbas are the backbone of our country's economy, not only during wartime, but also in peacetime, and at the same time are a source of potential environmental danger because the existence of most of them is hampered by the impossibility of further storage of beneficiation waste, both dry and liquid, in tailings ponds, which is complicated by the lack of land nearby for new storage facilities and the dangerous nature of the waste storage technologies used. In addition, known technologies for increasing the height of tailings dam walls no longer ensure their effective functioning, but only increase the environmental hazard of production. All this threatens to reduce the industrial potential of the regions, cause environmental disasters, and increase social tension when enterprises are shut down or land is expropriated.

The growing tension between the tech we make and the natural environment is really clear when you look at how mining companies work. Over many decades of operation of the Kryvyi Rih Mining and Processing Plant (MPP), huge amounts of beneficiation waste have been accumulated in tailings ponds covering an area of

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approximately 10,000 hectares, estimated at 5–8 billion tons with a total iron content of 14–18%, which can be considered man-made deposits [1–7].

Despite the comparative ease of development of such deposits, they are still unattractive due to the low ratio of useful minerals to waste rock, the burial of part of the useful minerals under embankment dams, which are being built up, and the unsatisfactory distribution of useful minerals across the tailings storage facility area, which necessitates their gross processing.

In this regard, the development of special measures aimed at more compact storage of beneficiation waste (formation of future man-made deposits) with an increase in the content of useful components to the level of natural deposits is highly relevant [5–8].

The aim of the work is to develop a classifier for beneficiation waste by selective extraction of useful components from the stream of beneficiation waste during their hydrotransportation from the beneficiation plant to the place of their separate storage for the formation of man-made deposits.

2. Methods

A distinctive feature of beneficiation waste is its large tonnage. The status of "waste" indicates the absence of currently economically viable technologies for extracting useful components in the main technological chain of existing production. Based on this, the localization of useful components should be carried out with minimal energy and material costs.

Therefore, an important direction for increasing the technogenic mineral resource base, while minimizing both costs and negative impact on the environment, is the development of a method for the selective extraction of useful components from the stream of beneficiation waste during their hydraulic transportation from the beneficiation plant to the place of their separate storage, which will ensure the formation of a man-made deposit with a high content of useful minerals [8–10].

3. Theoretical part

A review and analysis of literature sources showed that recent scientific and practical developments, which ensure an increase in the volume of useful components in the contours of existing tailings ponds, only partially solve this problem.

Work [10] presents the average granulometric composition of weathered tailings from the Central MPP tailings pond, which are transported by pipeline from the beneficiation plant (Table 1).

Analysis of the data presented in this table showed that in the fraction range from +1.00 mm to +0.25 mm, their mass fraction in the tailings is 40.9%, from which it is possible to extract only 19.3% of total iron and 9% of magnetic iron. The fraction range from 0.25 mm to less than 0.05 mm accounts for 59.1% of the total volume of beneficiation tailings, from which the extraction of total iron reaches 80.7% and magnetic iron 90.2%. The mass fraction of this fraction range, the content of total and magnetic iron, as well as their beneficiation, indicate their potential for additional beneficiation stage.

Table 1 – Granulometric composition of tailings from the Central MPP (2004)

Size classes	Mass fraction of fractions, %	Mass fraction of total iron, %	Mass fraction of magnetic iron, %	Extraction, %	
				Total iron	Magnetic iron
+1.00	2.9	11.1	1.7	1.1	0.3
-1.00 +0.63	7.1	12.1	2.9	2.8	1.4
-0.63 +0.45	11.1	12.7	3.0	4.6	2.3
-0.45 +0.25	19.8	16.7	3.8	10.8 (Σ=19.3)	5.2 (Σ=9.2)
-0.25 +0.16	22.1	27.9	10.1	20.2	15.3
-0.16 +0.07	12.5	38.3	16.3	15.6	14.0
-0.07 +0.05	5.1	42.2	25.1	7.0	8.8
-0.05	19.4	59.7	39.9	37.9 (Σ=80.7)	52.7 (Σ=90.8)
Total	100	30.6	14.6	100	100

In addition, this work presents the main minerals that make up the tailings: quartz 58.32% (ρ = 2.65 t/m^3), hematite 8.33% (ρ = 4.9÷5.3 t/m^3), magnetite – 7.60% (ρ = 4.8÷5.3 t/m^3), cummingtonite 6.85% (ρ = 3.1÷3.2 t/m^3), rhybecite 8.45% (ρ = 3.0÷3.24 t/m^3) etc.

To determine the possibility of separating the hydromixture flow into its constituent parts, the volume and mass of the useful component particles, as well as the barren rocks of various fractions of beneficiation waste, were determined (Table 2).

Table 2 – Volume and mass of useful component particles and barren rocks of different fractions of beneficiation waste

Fractions, mm	Particle volume, mm	Particle density $\rho_{p.c.}/\rho_p$, mg/mm^3	Mass of useful component particles/barren rocks, mg
+1.00	0.523	5.0/2.65	2.621/1.386
-1.00 +0.63	0.523÷0.131	5.0/2.65	2.621÷0.635/1.386÷0.347
-0.63 +0.45	0.131÷0.0478	5.0/2.65	0.635÷0.239/0.347÷0.126
-0.45 +0.25	0.0478÷0.0082	5.0/2.65	0.239÷0.041/0.126÷0.0217
-0.25 +0.16	0.0082÷0.00214	5.0/2.65	0.041÷0.0107/0.0217÷0.00567
-0.16 +0.07	0.00214÷0.000179	5.0/2.65	0.0107÷0.000898/0.00567÷0.000474
-0.07 +0.05	0.000179÷0.0000655	5.0/2.65	0.000898÷0.000327/0.000474÷0.000175
-0.05	-0.0000655	5.0/2.65	-0.000327/-0.000175

Analysis of the data in Table 2 shows the feasibility of dividing the flow of hydromixture from beneficiation waste into three components:

1) a potentially productive lower layer consisting of low-grade and difficult-to-beneficiate particles of medium and large rock fractions, which require additional fine grinding before reprocessing;

2) a productive middle layer consisting of rock particles containing components with the maximum amount of easily beneficiated useful components;

3) an unproductive upper layer consisting of particles of barren rock of small fractions.

The paper [11] presents a developed method for determining the weighing ceiling of particles of different density in a pressure suspension-carrying flow, which makes it possible to determine the height of the productive layer with the highest content of useful components in the cross-section of the total flow of beneficiation tailings that are transported for the purpose of its subsequent selective extraction to form a man-made deposit.

In addition, this work emphasizes that particles of even the same size class, depending on their physical and mechanical properties, are located at different heights (their weighing ceiling) in the transported flow, i.e., ore particles are located significantly lower than rock particles. Therefore, the upper limit of selective extraction of the productive layer will be determined by the weighing ceiling of ore particles of less than 0.05 mm in the hydromix flow, and the lower limit will be determined by the weighing ceiling of particles larger than 0.25 mm.

An analysis of literature sources [8–18] and published patents for inventions shows that existing installations designed to extract useful components from transported beneficiation waste have a number of significant drawbacks, the main ones being:

1) selection is carried out from a turbulent flow of hydromixture by sampling devices that cannot ensure the completeness and quality of the extracted components;

2) a significant part of the useful component is transferred to the tailings storage facility;

3) significant capital and energy costs associated with the purchase and maintenance of powerful laser equipment used to separate the hydromixture into fractions.

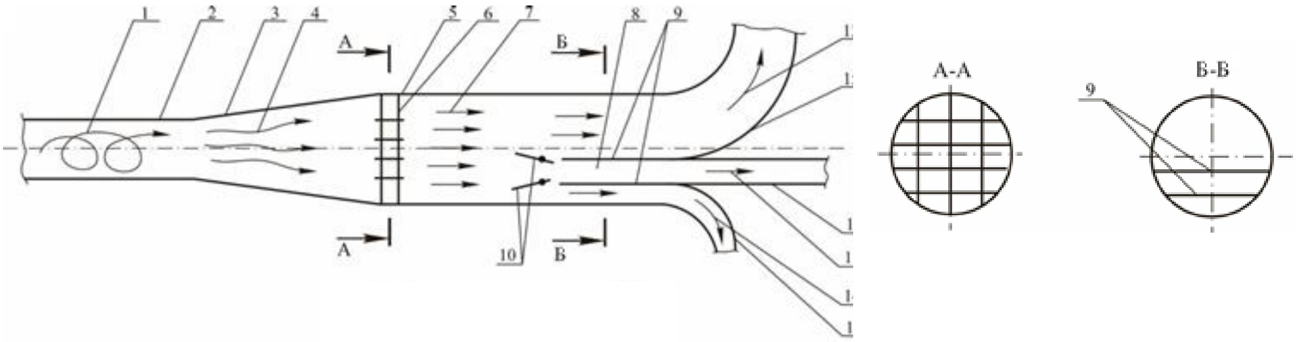
Based on the research conducted, a classifier has been developed that separates the flow of the beneficiation waste hydromixture into three components with selective separation of the productive layer. This classifier consists of a diffuser and a working chamber in which an aerodynamic grid and a productive layer receiver are installed.

The separation of the flow of the hydromixture of beneficiation waste with selective separation of the productive layer is carried out as follows (Figure 1).

First, the beneficiation waste is transported through a main pipeline and enters a horizontal diffuser. In this diffuser, the turbulent flow gradually slows down to an acceptable level and becomes stratified. The flow is then directed to the working chamber, at the entrance of which an aerodynamic grid is installed to stabilize the ceiling zone for particles of different densities and weights. In addition, in order to reduce the dynamic load on the internal structural elements of the working chamber and taking into account the requirement that the flow velocity at the outlet of the diffuser (V_{cr}) must remain not lower than the critical value, i.e. $V_p = (1.05 \div 1.1) V_{cr}$, the diameter of the working chamber connected to the diffuser is calculated using formula (1):

$$d_{w.c.} = \sqrt{\frac{d_p^2 \cdot V_p}{(1.05 \div 1.1) \cdot V_{cr}}} \text{ m,} \quad (1)$$

where d_p – diameter of the main pipeline, m; V_p – flow velocity of beneficiation waste in the pipeline, m/sec; V_{cr} – critical hydrotransportation velocity, m/sec.



1 – beneficiation waste; 2 – main pipeline; 3 – horizontal diffuser; stratified flow; 5 – working chamber; 6 – aerodynamic grid; 7 – flow of particles of different densities; 8 – receiver for selecting the productive layer; 9 – horizontal plates; 10 – adjustable louvers; 11 – productive layer; 12 – pipeline, 13 – unproductive upper layer; 14 – potentially productive layer; 15 – pipeline; 16 – pipeline

Figure 1 – Classifier for selective extraction of the productive layer with useful components from transported waste

Selective extraction of valuable components from a stratified stream of beneficiation waste, in which the weighing flows of particles of different densities are stabilized, is carried out in a working chamber equipped with a receiver for selective extraction of the productive layer. This receiver consists of two horizontal plates, the height of which is determined by the boundaries of the upper and lower weighing flows of ore fractions of different sizes [5].

In addition, these plates are equipped with adjustable louvers that allow for controlled extraction of the productive layer taking into account variations in its height, which depend on the physical and mechanical characteristics of the ore mined in the quarry.

This placement of the receiver for the selective extraction of the productive layer in the working chamber allows the total flow of the hydromixture of beneficiation waste to be divided into three separate fractions. Each of them differs in the content of the useful component and the physical and mechanical properties of the rock particles stabilized by the height of the flow.

The selectively extracted productive layer is transported via a separate pipeline and stored in a specially formed man-made deposit. Similarly, the potentially productive layer, selectively extracted, is transported through a pipeline and placed in a separate section of the formed waste storage facility. The upper unproductive layer of the flow is transported through a pipeline to the tailings storage facility.

Let us consider the effectiveness of the developed technology, which provides for the separation of the hydromixture and the selective extraction of the layer with a valuable component in order to form an artificial deposit. The separation of the hydromixture flow is carried out taking into account the beneficiation properties of the ore components: difficult-to-beneficiate and easily beneficiated, which belong to different fractions of the beneficiation waste (+1.0 ÷ +0.25 – difficult-to-beneficiate, -0.25 ÷ +0.05 – easy to beneficiate), as well as depending on their qualitative and quantitative composition.

Based on the data in Tables 1 and 2, we will analyze the granulometric composition of the separated layers of the hydromixture obtained from beneficiation waste. The results of the corresponding calculations are presented in Table 3.

Table 3 – Granulometric composition of the separated flow of hydromixture from beneficiation waste of the Central MPP

Layers separating the flow of the hydromixture	Grain size classes, mm	Mass fraction of fractions, %	Mass fraction of particles containing total iron, %	Mass fraction of particles containing magnetic iron, %	Mass fraction of barren rocks, %
Potentially productive	+1.00	2.9	11.1	1.7	88.9
	-1.00 +0.63	7.1	12.1	2.9	87.9
	-0.63 +0.45	11.1	12.7	3.0	87.3
	-0.45 +0.25	19.8	16.7	3.8	37.5
Productive	-0.25 +0.16	22.1	27.9	10.1	94.5
	-0.16 +0.07	12.5	38.3	16.3	84.1
	-0.07 +0.05	2.15	71.6	25.1	28.4
	-0.05	9.83	100	39.9	0.00
Unproductive	-0.06 +0.05	2.95	0.00	0.00	100.0
	-0.05	9.56	0.00	0.00	100.0

A comparative analysis of the potentially productive and productive layers shows that, with virtually identical mass fractions of their fractions in the beneficiation waste (40.9% and 46.58%, respectively), the mass fraction of easily beneficiable particles of fine fractions containing total iron in the productive layer exceeds by 2.5–3 times the mass fraction of difficult-to-beneficiat metal-containing particles of medium and large fractions of the potentially productive layer, and the mass fraction of particles containing magnetic iron is almost 10 times higher. At the same time, the mass fraction of barren rocks in the productive layer is 1.5–1.8 times less than in the potentially productive layer. The unproductive layer, whose mass fraction is 12.5%, consists only of barren rocks. It should be noted that the parameters of the granulometric composition of the beneficiation waste of the Kryvbas MPP can vary significantly from each other, and therefore it is necessary to determine the upper limits of the weighing of mineral particles and the qualitative composition of each of the separated layers of the hydromixture based on the actual indicators of each MPPs.

4. Conclusions

Based on the results of the research, a classifier was developed for the selective extraction of a productive layer with a useful component from the total flow of the hydromixture. The use of this classifier will ensure the formation of a man-made deposit with a high content of useful minerals. Based on the results of the research, a patent for a utility model No. 156577, Ukraine, IPC B 038 9/06 “Method for selective extraction of a productive layer with a useful component from transported beneficiation waste” was obtained. Published on 10.07.2024. Bulletin No. 28 [19].

Conflict of interest

Authors state no conflict of interest.

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РОЗРОБКА КЛАСИФІКАТОРА ВІДХОДІВ ЗБАГАЧЕННЯ ДЛЯ ФОРМУВАННЯ ТЕХНОГЕННИХ РОДОВИЩ

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Анотація. Авторами в статті розглянуто сучасний стан хвостосховищ гірничо-збагачувальних комбінатів Кривбасу, наведені гранулометричний склад лежалих хвостів Центарального ГЗК, об'єм та маса частинок корисного компоненту і «порожніх» порід різних фракцій відходів збагачення. Досліджено, що за багато десятиліть роботи Криворізьких ГЗК у хвостосховищах, що займають площу приблизно 10 тис. га, скупчилися величезні маси відходів збагачення, які оцінюються в 5–8 млрд. т із вмістом загального заліза на рівні 14–18%, і можуть вважатися техногенними родовищами.

За результатами досліджень визначено, що сьогодні для сталого розвитку Кривбасу важливим напрямком є вилучення техногенної мінеральної сировини з хвостосховищ, як сформованих техногенних розсипів в процесі складування відходів збагачення, за рахунок мінімізації як витрат, так і негативного впливу на навколишнє середовище. Тому розробка класифікатора відходів збагачення для формування техногенних розсипів за рахунок селективного відбору корисного компонента з потоку відходів збагачення в процесі їх гідротранспортування від збагачувальної фабрики до місця їх роздільного складування.

Встановлено, що масова частка «порожніх» порід продуктивного шару менша в 1,5–1,8 рази від потенційно-продуктивного. Непродуктивний шар, масова частка фракцій якого дорівнює 12,5%, складається тільки з «порожніх» гірських порід. За результатами проведених досліджень встановлено, що параметри гранулометричного складу відходів збагачення ГЗК Кривбасу можуть значно відрізнятись один від одного, а тому визначати межі стелі зважування частинок мінералів і якісний склад кожного з розділених шарів гідросуміші необхідно визначати за фактичними показниками кожного з ГЗК. Розроблено класифікатор, що забезпечує розділення потоку гідросуміші відходів збагачення на три складові частини із селективним відбором продуктивного шару. Використання розробленого авторами класифікатору для селективного відбору продуктивного шару з корисним компонентом із загального потоку гідросуміші дозволить досягти поставленої мети, а саме: забезпечення можливості формування техногенного родовища з високим рівнем вмісту корисної копалини.

Ключові слова: відходи збагачення, лежалі хвости, гранулометричний склад, класифікатор, продуктивний шар